RESOURCE MANAGEMENT POLICY FOR NON-COMBAT VEHICLES FOR THE ARMED FORCES OF THE REPUBLIC OF CHINA

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THESIS

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OF THE REPUBLIC OF CHINA

by

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inefficient manner as compared to those produced in the United States. A logical alternative to reduce the cost is to combine the total demand and try to seek more efficient production Unlike the private market, military vehicle replacement decisions are centralized. The rate of replacement largely determines the number of vehicles required by the military. To help the decision maker to gain some insight on the optimal lifetime of a motor vehicle, a stochastic model is suggested in the paper.

Resource Management Policy for Non-Combat Vehicles for the Armed Forces of the Republic of China

by

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ABSTRACT

The Armed Forces of the Republic of China have a large number of motor vehicles for administrative use. The vehicles were acquired from different sources in different years. In general, the vehicles are old in age. The Armed Forces have established a plant to manufacture vehicles for replacement. Because the volume of production was low, the unit cost tended to be high. The private industry motor vehicles were also produced in an inefficient manner as compared to those produced in the United States. A logical alternative to reduce the cost is to combine the total demand and try to seek more efficient production. Unlike the private market, military vehicle replacement decisions are centralized. The rate of replacement largely determines the number of vehicles required by the military. To help the decision maker to gain some insight on the optimal lifetime of a motor vehicle, a stochastic model is suggested in the paper.

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I. INTRODUCTION

The Armed Forces of The Republic of China (AFRC) have a large number of motor vehicles for non-combat, administrative use. The exact number of the vehicles is unknown until a local investigation is made. In this study current data limitations are of two types: security, and simple non-existence of a sophisticated data base. Unfortunately, it is not possible to separate these at this time. According to official statistics, the total number of the Armed Forces is around six hundred thousand. [1] It is reasonable to believe that the number of motor vehicles is quite large, since the U.S. Army, on which the AFRC is modeled, has approximately one vehicle per active duty soldier. [2] For the purpose of discussion in this paper it could be assumed that the total number of non-combat type vehicles is not less than 30,000 units.

The motor vehicles were acquired from different sources through the years. Some were carried over from the mainland and some were from the excess stock after different Asian area wars. Many of the motor vehicles are very old. For some time, the Armed Forces have had an extensive maintenance capability on Taiwan to repair the worn-out vehicles or to cannibalize them in order to maintain others. This capability is further discussed in Chapter IV. Because the total number of vehicles was still considered inadequate, the Armed Forces more recently established a manufacturing plant to fabricate their own vehicles, as discussed in Chapter IV.

How high the actual cost is for maintenance of the vehicles has long been questioned. The manufacturing cost of vehicles tends to be high because the volume of production was small and the expensive plant facilities were not fully utilized. Although hampered by lack of data, those questions are addressed in this paper at a policy level and with a simple model.

It is suggested that the defense economy is a part of the national economy and must be addressed as part of the whole. In this case, in relation to the national automobile industry. For many years, the national economy boomed continuously. In 1954, the first manufacturer for motor vehicles was established when the national income per capita was around US$100. By 1974, the national income per capita was up to US$700 and there were six independent car manufacturers. However, all the private manufacturers have had some difficulty. Every one of them selected several models of vehicles to produce in trying to dominate the local market. Consequently, the production output of each model was very small. For most of them, the total annual production was less than one thousand units. The result was that the unit cost of the vehicle tended to be too high.[1]

Many indications show that the need for motor vehicles is expanding. The Armed Forces replacement needs are becoming urgent now that the Asian area war no longer is a source.

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[1] Central Daily News, Taipei, 17 Dec 1974, p. 1. A recent official investigation into the auto industry reported that the utilization of plant facilities was about 30%.

The highway authorities reported that the total number of civilian motor vehicles increased with an average annual growth rate of 16.26% for fifteen years.

In 1973, the total number of civilian vehicles was 1,400,000 units.[2] There is a prospective market for motor vehicles since this is still less than one vehicle for 11.4 people.[3]

A logical solution to the problem seems to lie on the supply side. How the private auto industries can achieve the advantages of economies of scale and full utilization of plant remains a national economic question.

The subject of this paper is to try to put a focus on this potential accommodation between the sectors of demand and of supply. The automobile industry needs advanced technology as well as intensive capitalization which, in turn, is gradually built up by economic achievement. Therefore, some aspects of economic development are important to this question and will be addressed in the next chapter.

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[2] Sources: Ministry of Communication, Government of Republic of China and the Taiwan Highway Bureau. The average 16.26% was computed base on the data from 1958 to 1972.

[3] Population in Taiwan is 16,000,000.

II. NATURE OF THE PROBLEM

A. GENERAL NATIONAL BACKGROUND

Taiwan as an island watches the gate to the free world in the Pacific and is also one of the provinces of the Republic of China. Back in 1903, China surrendered Taiwan and the Pescadores to Japan after a war. During WWII the U.S. Air Force bombarded the islands trying to destroy the Japanese military as well as the industrial facilities on the islands. In 1945, the war ended and Japan returned the islands to China. In 1949, Russian-supported Chinese communists took over the mainland and the central government of the Republic moved to Taiwan. By that time, every aspect of the island was in bad shape.

U.S. economic aid to the country started in 1951 through the commission of the Agency for International Development (AID). The aid was a vital transfusion which motivated the economic activities in the island. The economic aid terminated in 1965. It had turned out to be one of the most successful cases of U.S. foreign aid. [3]

The private industries began to assemble motor vehicles of various types with imported Japanese parts in 1952. Many of them actually were very small machine shops. Technologically speaking, they were handcraft shops and had a very low production rate of six to eight units or even less in one month. Their products were primarily trucks for agriculture.

A real manufacturing plant equipped with modern facilities for motor vehicles opened in 1954. And the Ministry of Economic Affairs (MOEA) set up a policy based on the "ratio of self-manufactured parts' to regulate the industry. This rule played an important part in the national economic growth, as seen in the following sections.[4]

B. ECONOMIC RECOVERY AFTER WWII

1. Before 1951

It was reported that on V-Day in 1945 when Taiwan was retroceded to the Republic of China, about three-fourths of the industrial facilities and two-thirds of the electric power generating units were incapacitated, and only one-fourth of the highways remained serviceable. Harbors were ruined and blocked. As a result, agricultural output dropped to forty-five percent and industrial output to less than one-third of their pre-war peaks. [4]

A painful process of rehabilitation and reconstruction began right after the war. In the first two years, the recovery of agricultural and industrial output was very slow. Unemployment of unskilled labor continued to increase.

In 1949, the central government of the Republic transferred its seat to Taiwan and brought along a large number of mainlanders, mostly well educated. Many had administrative,

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[4] "Ratio of self-manufactured parts" means a fraction or percent, calculated by cost, of the automobile parts which must be made domestically. Periodically, MOEA sets up different rates for various manufacturing products, such as TV sets, refrigerators, computer assemblies, machine tools, etc.

managerial, and technical knowledge and experience. The impact of this change upon Taiwan's economy was enormous.

The economy started increasing. According to Prof. M. H. Hsing [5], in 1953 the adjusted real income per capita had reached the Japanese occupied prewar highest level. Some figures from his book follow:

TABLE I

National Income Per Capita, Taiwan Area (1935-1953)

Base Year	Local Currency	US$	US$ Adjusted to Base Year
1935	Japanese Yen 139.5 (1935)	40.1 (1935)	40.1 (1935)
1951	New Taiwan $3,911 (1964)	85.39 (1964)	38.10 (1935)
1952	$4,221 (1964)	92.16 (1964)	41.47 (1935)
1953	$4,334 (1964)	94.63 (1964)	42.58 (1935)

2. U.S. Aid to Taiwan

With the arrival of U.S. aid, the powerful Economic Stabilization Board was established in 1951. The often heard phrase "developing agriculture by virtue of industry and fostering industry by virtue of agriculture" was not merely a political slogan but a guideline of action for the government. As a matter of fact, systematic development of agriculture began earlier under the careful planning of the Sino-American Joint Commission on Rural Reconstruction (JCRR).

The United States' aid program had played a decisive role in Taiwan's economic development and industrial development.

Its immediate objective was to stabilize the inflation and then shift its emphasis from economic stabilization to economic development.

According to Professor M. H. Hsing [5], taking all forms of U.S. aid together the total delivered was US$1370.2 million from 1951 to 1965.

From a no-aid growth model constructed for Taiwan based on a number of simplifying assumptions, Professor N. H. Jacoby [3] drew the following startling assumptions:

> "Aid more than doubled the annual rate of growth of Taiwan's GNP, quadrupled the annual rate of growth of per capita GNP, and cut thirty years from the time needed to attain 1964 living standards. Without aid, it was calculated that the GNP would have grown only 3.5 per cent a year until 1983, and in 1964 would have been only about 58 per cent of the actual amount. Actual per capita GNP of 1964 would not have been produced until 1995."

It was somewhat difficult to pass judgement on the above conclusion because the validity depends on the assumptions underlying the models that Prof. Jacoby used. Nevertheless, it was a very successful economic achievement.

3. <u>To Achieve More Prosperity</u>

The aid program terminated in 1965. Apart from directing the use of U.S. aid, the Chinese Government has adapted a wide spectrum of policies for economic development and national industrialization. The major policies could be conveniently grouped into six categories. They were:

a. Direct control over industry;
b. Foreign trade and exchange control;
c. Tariff protection;
d. Export promotion;
e. Encouragement of investment;
f. Provision of finance.

Since 1953 a four-year economic development plan comes out every four years. The Chinese government has implemented a series of consecutive four-year economic plans for further prosperity. During the first and second planning periods, targets were the development of the industries of import substitution. After the third and fourth planning periods, the volume of exports expanded enormously. Heavy industries are emphasized in the sixth four-year plan, launched in 1973 and to be accomplished by 1976.

The continuously increasing achievement of economic development cultivated an appropriate climate for the automotive industries to sprout and to flourish. The climate is better described by figures which give the national income per capita adjusted to 1966 base value. (See Table II).

C. GROWTH OF DOMESTIC AUTO INDUSTRY

1. The Yue-Loong Motor Company Period

In 1952 the Taiwan adjusted national income per capita was around US$106.[5] There were many small machine shops which started to assemble different kinds of trucks of various sizes. Most of them were three-wheelers with a small diesel engine installed which originally was designed for fishing boat use. Owing to their poor stability, three-wheelers were banned. The manufacturers who wanted to stay in the business had two

[5] Source: Directorate-General of Budgets, Accounts and Statistics (DGBAS), Executive Yuan, Government of the Republic of China. At 1966 prices, the 1952 adjusted real income per capita was NT$4,277 and the official exchange rate to US$ in the cited year was NT$40.10 to US$1.00. 4277 ÷ 40.1 = 106.6.

TABLE II

National Income Per Capita, Adjusted to 1966 Base Value

(1965 - 1973)

Year	1965	1966	1967	1968	1969	1970	1971	1972	1973
NT$ (1000)	7.35	7.67	8.25	8.68	9.14	9.95	10.8	11.6	12.6
Economic Growth Rate, Percent*	3.5	4.4	7.5	5.2	5.2	8.9	8.8	7.5	8.4
Manufacture Ind. Growth Rate, Percent**	19.6	16.4	18.1	23.8	18.9	18.3	22.7	27.7	24.5

* Source: Directorate-General of Budget, Accounts and Statistics, (DGBAS), Executive Yuan, Government of Republic of China.

** Source: Ministry of Economic Affairs (MOEA).

ways to go, either to two-wheel or four-wheel. For the former case, some manufacturers acquired foreign technical cooperation to make motorcycles.

Because of the influx of foreign technology, the government set up a "ratio of self-manufacture" for all manufacturing industries to control the specific industry. According to the ratio, some parts must be made domestically. Every year the government reviewed the situation and readjusted the ratio accordingly in order to bring up a broader development of industry.

The motorcycle industries boomed until the government changed its policies in response to social pressures against motorcycles and for traffic safety considerations.

The Yue-Loong Motor Company made the first jeep under a license authorized by Willys of USA in 1957. The next year Yue-Loong contracted with Nissan Motor Co. of Japan to assemble Nissan's "Blue Bird," a 1,100 cc four-door sedan, in Taiwan. At first, Yue-Loong agreed to increase the percentage of domestic made parts by ten percent annually. But later in 1962, the Ministry of Economic Affairs (MOEA) revised the ratio for auto industry to sixty percent as a ceiling for the time being.

In 1964, Yue-Loong announced that the annual production of "Blue Bird" was one thousand units while the total assets of the company were one thousand million dollars (in New-Taiwan currency), which was equivalent to US$25 million in that year. It employed two thousand workers.

It is a general belief that a sound automobile industry is a doorway to overall industrialization of an economy. The automobile industry is highly intensive in capital, in precision technique, and in modern management skill. Yue-Loong started the business almost in a semi-handicraft way. It had a hard time. However, it dominated the domestic market for several years. With the continuous upward climb of real income per capita reaching US$217.00,[6] other manufacturers started to join in.

Another manufacturer, San-Fu Industrial Company, registered a capital of NT$12 million in 1964 and produced small trucks and small sedans which Japanese Subaru licensed. At the end of 1969, its total assets were estimated to be NT$60 million. San-Fu is the smallest of the four auto manufacturers in operation, yet it is the only one whose sales of 1970 exceeded those of 1969.

San-Yang Company is a manufacturer licensed by Honda of Japan. In late 1968 it shifted its business from motorcycle to automobiles and reorganized with total assets of NT$800 million. The company announced that it would specialize in the production of heavy duty trucks.

Lio-Ho Industry Corporation registered in 1965 having a cooperation contract with Japanese Toyota. But the actual production began in 1971 with 6,000 units of Corona annually. In 1973, after Lio-Ho terminated the cooperation with Toyota, Ford Motor Company of USA invested in the corporation and reorganized it.

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[6] Source: PGBAS op. cit. For the year 1968, and calculated as the footnote on P.

There were others in the industry, but Yue-Loong remained the most important one during this period.

2. The Ford-Lioho Motor Company Period

In 1973, Ford Motor Company of USA acquired seventy percent of the old Lio-Ho shares in an amount of US$6,300,000. They reorganized the corporation into Ford-Lioho Motor Company. Ford Company also announced a first-stage ten-year development plan for the newly established subsidiary. The plan consists of four phases: in phase I, from 1973 to 1974, Ford would invest US$6,900,000 for plant and machine tools; in phase II, from 1975 to 1977, another US$6,200,000; in phase III, from 1978 to 1980, US$10,040,000 more; and the last phase ends in 1983, with an investment of US$16,400,000. The total amount of the ten-year plan sums up to thirty-nine million in US dollars. [6].

Ford-Lioho plans to specialize in sedan production. According to the plan, there will be four different types of cars produced. They are: Fiera, a special design for Asia, of 1,100 cubic centimeters' (cc) displacement, with annual production of 4,000 units; Escort, 1,300 cc, annual production of 1,600 units; Cortina, 1,600 cc, 2,900 units; and the luxury line of Fairmont and Walnut with an engine displacement bigger than 5,000 cc, for export.

According to a newspaper, Ford-Lioho introduced its first Cortina to the Taiwan market several months ago.[7]

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[7]Central Daily News, Taipei, International Edition, some day in June or July 1974.

3. The Satellites of the Auto Industry

A modern motor vehicle consists of more than one hundred major assemblies which are in turn made up of many parts of different materials. The whole process requires a huge diversification of production. Even in many highly-developed countries, such as USA, Japan, or Germany, many car manufacturers merely assemble a car using the parts provided by contracted vendors. It is a general principle that the three "S's" (specialization, simplification, standardization) lead to economical production. In other words, it would be economical to specialize the technique as well as to divide the labor for larger volume of output with less product varieties.

The name, Satellite Industries, is used by the Ministry of Economic Affairs (MOEA), for those who make parts and contribute them to a major industry. The satellites still have their own line of distribution, for instance, a rubber tire company not only is a vendor to a car manufacturer but also accepts its own export orders.

With the appearance of car manufacturers came many more parts manufacturers. According to a survey made by the Bureau of Industry, MOEA [7], at the end of 1971 there were 31 machinery factories making qualified automobile parts, such as, hydraulic cylinders, pistons, piston rings, crankshafts, mirrors, radiators, bearings, springs, instruments, batteries, starters, etc.

Playing a support role to different manufacturing industries, there are the primary industries, namely, the iron foundries that make the castings and the rolling plants that make beams and sheets.

Industries of glass, rubber, and plastic are also major satellites to the auto industry. In Taiwan, these three industries were always at the top of the list of profit makers, even before the auto industry existed. For a long time, all of their products had a very good quality level as well as a very good reputation in the international market. These industries had no difficulty in supporting the developing auto industry. This is in contrast to the situation in some other countries where auto industry development was slowed by lack of supporting industries.

D. AUTO INDUSTRY ANALYSIS

For many years the price and low quality of domestic cars has been criticized throughout the country. It seems that the one way to reduce production cost and assure better quality is to try to acquire the advantage of economies of scale. Large scale streamlined manufacturing processes requiring more and better use of capital are needed. Apparently this is the Ford Motor Company's intent with its subsidiary Ford-Lioho in Taiwan.

Taiwan is not a very big territory.[8] It is hard to justify several dozen different types of cars on its 17,000 kilometers

[8] The island is leaf-shaped, 450 km from north to south, 150 km from east to west in the middle part.

of highway. The production of many diverse models, each with low volume of output, has led to inefficient production.

The author would assume that in the United States the production of motor vehicles, after a period of longer than sixty years, has already approached an efficient stage of production. In order to have an indicator to support the assumptions of current inefficiency in the Taiwan auto industry noted above, a ratio of "total assets per car output" was computed for motor vehicle manufacturers in the United States. Due to the incompleteness of data resources, it was a somewhat rough comparison.

Table III shows the total assets and number of cars sold per year for Ford and General Motors in the USA. A ratio of total assets per output was computed by year. The mean value of the eight data points was found to be 2.2445. In a sense, there were US$2,244 of total assets value per car output for an American car manufacturer.

TABLE III

Total Assets Per Car Output in the United States

Year:	1969	1970	1971	1972
Ford				
Total assets in million US$	9,199	9,904	10,509	11,634
Cars sold in thousand units	4,944	4,862	5,024	5,698
RATIO	1.860	2.037	2.091	2.041
General Motors				
Total assets in million US$	14,820	14,174	11,048	12,145
Cars sold in thousand units	5,259	4,609	5,767	5,740
RATIO	2.818	3.075	1.916	2.116

Applying the same criterion to Yue-Loong, for the year 1964 the ratio appeared to be 25.0, which was eleven times the American average. Yue-Loong's 1964 data was the only available data for making a comparison to the United States average; admittedly, it is a crude comparison. In 1964, Yue-Loong's total assets were US$25 million while the planned annual production was 1,000 units of "Blue Bird.". However, according to Taiwan Highway Bureau's report in the year 1964 domestically manufactured vehicles were 1,797 units. Assuming that all 1,797 units were made by Yue-Loong because the other manufacturers joined in the business after 1967, the ratio turned is 13.9. This is 6.2 times the Americans' average, still a sizeable difference.

A similar comparison was made using manpower ratios. This is shown in Table IV, which can be compiled according to relevant annual reports. Both tables show relatively consistent results. Applying the same procedure to Yue-Loong's 1964 situation turned out as the number 24, which reveal that for one car output Yue-Loong needed 24 times more manpower than Ford. For every one manpower input, Ford made 24 times more cars than Yue-Loong.

TABLE IV

Manpower Productivity in the United States

	1969	1970	1971	1972	Average
Workers employed by Ford in USA	244,840	229,404	225,304	232,869	
Men/car output	.0495	.0472	.0448	.0409	.0456
Cars/man input	20.19	21.19	22.29	24.47	21.92

- -

Yue-Loong compared to Ford:

Cars manufactured -	1,797	
Workers employed -	2,000	
Men/car output -	1.113	1.113
Cars/man input -	.899	

$$1.113 \div .0456 = 24.4$$

$$21.92 \div .899 = 24.4$$

- -

The author believes the ratios are an indication of different economic structures, i.e., sizes rather than a consequence of totally disorganized inefficiency. On the average, the hourly wage rate for a U.S. auto worker is around \$4 to \$5 and the national income per capita is almost US\$4000. In the Republic of China the national income per capita is US\$700 and the auto worker is paid by month or day. His daily wage rate is around NT\$500, equivalent to US\$13.

The lower wage rate and the import tax on foreign-made automobiles allow the domestic auto makers to compete with foreign-made automobiles. However, a large production rate should result in better utilization of capital and labor, thus lowering cost and thereby expanding demand.

III. PROBLEMS TO BE SOLVED

In Taiwan the demand for motor vehicles is substantial. The Armed Forces have a large potential demand, as mentioned earlier. In the open market the booming economy created a demand for more cars. In Table V the growth of motor vehicle production can be seen.

TABLE V

The Growth of Motor Vehicle Production in Taiwan

Year:	1968	1969	1970	1971	1972
Cars made	7,670	10,890	7,871	10,917	19,618
Increased by Percent [9]		41.9	-27.7	38.7	79.7

Domestically-made cars have long been criticized for their high cost. Probably the most important problem to be solved would be the reasonable reduction of the production cost. Some suggestions for consideration are:

(1) Reduce the various types of cars to fewer standard models.

(2) Encourage the individual manufacturers to merge so that they could pool their capital to utilize modern mass production techniques.

(3) Introduce professional management systems to acquire the higher efficiency of production.

(4) Further specialize the production of standard parts. There are some specialized manufacturers already, e.g., makers of radiator springs, pistons, piston rings, etc.

[9] Starting from 1970, import of foreign-made cars was allowed. There was a major impact only in the first year.

Further specialization, especially in automatic production facilities and advanced techniques, remain to be introduced.

(5) Explore the potential industries which are vertically related to the auto industry for more efficient production.

With regars to item (1), the standard models should be designed for potential use. The author strongly feels this to be a very important policy to apply to today's Taiwan situation in which the natural resources are very limited. For many years most of the vehicle manufacturers produced motor vehicles according only to the contracted license to make the same car designed in a foreign environment for their specific demand. None of the manufacturers designed a vehicle according to the domestic environment. The Farmer's Association in Taiwan already has made the claim that the farmer working in Taiwan's fields needs a car fit to his requirement. [8]

Probably the main reason for the diversification of car types is the competitive pressure from the market. The author had an intuition that most people were seeking economy cars. The Volkswagon Beetle, which sells well in Taiwan, is a good example. An alternative is to select a few good designs and put them into mass production in order to achieve the advantage of cheaper unit cost.

In Taiwan, where the highways in general are good, a truck good for commercial use is also good for administrative use. A jeep good for the Armed Forces is also good for forest police. The author emphasizes that many small individual demands could be pooled into a large demand which would make

possible mass production of a standard vehicle. It would be even better if the Armed Forces would purchase mass produced vehicles from private auto manufacturers.

The above suggestions are somewhat related to each other. For a highly automatic plant for mass production, intensive capital as well as professional management systems are essential. These were mentioned in points (2) and (3) respectively.

Referring to the last point, there are actually many aspects which could be explored. For instance, the plastic industry in Taiwan has been the most profitable for years. If the plastic industry would invest some of its research and development capability on potential usage of plastic for motor vehicles, it might reduce the cost of a vehicle in the future. Downward vertical integration of auto industry could lead to car rental services, which in turn might stimulate larger demand for cars. A full development of the auto industry could lead to regional international cooperation. For instance, in Asia, Japan is highly developed while there are many countries in the "take-off" stage of development. Cooperation based on mutual benefit is feasible. For instance, each country manufactures certain auto parts with the advanced countries making the complex parts and the others concentrating on labor-intensive parts. The countries exchange the parts and every country, or group of countries, assemble the cars for their own use. This might be an economical way to acquire motor vehicles. However, further development is far beyond the scope of this paper.

IV. A MATHEMATICAL MODEL TO HELP DECISION MAKING

A. CURRENT AFRC VEHICLE POLICY

Almost twenty years ago the Armed Forves of the Republic of China (AFRC) established several maintenance shops spread over the island in order to keep the vehicles in good shape. A few years later a large base depot for overhauling as well as cannibalization of vehicles was installed. Then, five or six years ago another brand new automobile manufacturing plant was set up to fabricate vehicles for replacement, as mentioned previously. The author believes that the number of vehicles needed to be replaced outnumbers those the manufacturing plant could supply. The output volume of the manufacturing plant is low, say, less than 1,000 units per year. The limitations arise from many reasons, for instance, lack of working capital, lack of cost consciousness, lack of skillful workers and lack of entrepreneurship.

If all the AFRC's demand could be added to civilian demand to form a unique national demand it would help the market to expand. This might allow the producers to adopt the advantages of the economies of scale.

The AFRC demand is primarily for replacement. The nucleus of a replacement problem is the cost incurred. According to engineering economic theory of replacement, a piece of machinery should not be used as long as the marginal cost is below the average cost. When marginal cost exceeds average cost, a

replacement should take place. [9] In practice, the next year's operating cost, including maintenance cost, is compared to the annualized investment cost plus average operating cost of a new vehicle.

It seems that AFRC does not have a significant replacement policy for its administrative vehicles. It does not have data on each vehicle's costs. On the other hand, when the number of vehicles is large, the general engineering economy type technique is hard to apply on a vehicle-by-vehicle basis. A general policy on replacement by age or usage is needed.

For the cost of keeping all vehicles usable, the total expenditure for the maintenance facilities should also be included. In other words, the maintenance cost of a vehicle is not only the materials replaced and labor applied, but also the opportunity cost of doing something else. For example, at present it is necessary for military mechanics to manufacture repair parts for old vehicles. The cost to their time is hidden in the fixed cost of the military units. The author would contend that two procedures should be implemented. First, a thorough study should be made of the total current expenses for the upkeep of cars. The actual money spent, no matter what budget category it is from, should be stressed. The investigation might turn up something dramatic in the way of high maintenance costs. Secondly, let AFRC buy a group of standard commercial trucks and set up a unique record system to trace all the expenses that were incurred; applying the standard engineering economic replacement rule will generate

observation of the lifetime of the vehicles. After the data is collected, some statistical analysis techniques could be applied, as seen in the next section, and some knowledge of the cost behavior of the vehicles could be deduced. Probably the two procedures could be performed simultaneously.

Military standards are difficult to achieve by the rather primitive private industry. The cars used by AFRC were highly sophisticated and need advanced technical capability to assure the quality requirements. The author strongly supports the requirement for a combat vehicle that is engaging in a dog-fight over an unexpected terrain. However, the military does not need a truck with water-tight, super-tough chassis, high traction, equipped with complicated multi-fuel engine, to face the blinking traffic lights on a well paved asphalt highway. It would be better to design a model according to the requirement.

If it is decided to depend upon private industry for the AFRC's vehicle demand, the AFRC could turn its vehicle manufacturing capability to production of combat vehicles and to its Research and Development use. For instance, it could be used to develop prototype vehicles to meet future missions. It could provide the capability for pilot production, to collect cost data and apply some systems analysis techniques to study the cost behavior. For instance, many still do not believe that the production cost of some manufacturing items will go down when the production volume increases. The learning curve theory, for example, as related to specific working conditions

could be validated by production experimentation. The Research and Development (R&D) facility could make and supply to the industry the production jigs and fixtures, the measuring tools and gauges for on-line inspection or for product quality assurance. This is simply an application of the principle of division of labor. The author is convinced that this is the principle that can help the production cost of a vehicle to come down and that the national technological level can be escalated. These relationships between private and military facilities would be novel and perhaps require considerable experimentation.

B. A SUGGESTED MATHEMATICAL MODEL

1. Stochastic Aspect

As stressed in the above section, the cost behavior of vehicles and life-cycle factors should be observed before any decision for replacement policy could be made. A model for minimization of average lifetime cost of a vehicle is proposed in the next paragraph. This model leads to a general policy on vehicle lifetime. The advantage of a policy is the generality of association. As stated in the title of this paper, the focus is not for a single vehicle but rather for a group. For a relatively large number of vehicles with the cost in a long run perspective, a model with stochastic aspect is suggested because costs will be incurred with some random elements.

2. <u>A Model for Minimization of Long-Run Average Cost</u>

Suppose that the lifetime (years) of a motor vehicle is a continuous random variable, t, having a probability density function (pdf), f(t), and a cumulative distribution function (cdf), F(t),

where

$$\int_{-\infty}^{+\infty} f(t)dt = F(t) \tag{1}$$

As a matter of fact, the lifetime of a motor vehicle starts at t = 0, and the lifetime is rarely longer than 20 years; therefore equation (1) can be rewritten as

$$\int_{0}^{20} f(t)dt = F(t) \tag{2}$$

Arbitrarily on the time scale, set a point T such that 0<T<20. And assume there is a policy that as soon as a vehicle either breaks down or reaches the age of T years a brand new vehicle replaces the old one.

The object of this study is to find the optimal policy for vehicle retirement which would minimize the lifetime average cost of a motor vehicle.

(1) Total lifetime cost for one vehicle

K purchase expenditure, a single payment made at t=0;

c(t) operational and maintenance cost, is a continuous function of time and could be assumed to have a general form of

$$c(t) = c_0 + c_1 t + c_2 t^2, \quad \text{for } t \geq 0$$

c_i is the cost coefficient

s(t) the salvage value, which decreases as a function of time. It is a reduction to the cost so it is subtracted. It could be assumed to have a general form of

$$s(t) = s_o - s_1 t - s_2 t^2 \ , \text{ for } t \geq 0$$

s_i is resale value coefficient.

h(t) extra operational cost above T, a continuous function of time. When a vehicle's age is up to point T and it does not break down, it will be kept in use but not any maintenance will be applied. It could be assumed to have a general form of

$$h(t) = h_o + h_1 t + h_2 t^2 \ , \quad t > T$$

h_i is extra operational cost coefficient.

Now, let random variable t be the lifetime of a motor vehicle for an arbitrary lifetime cycle, then the incurred costs during the cycle will be

$$K + c(t) - s(t) \ , \quad \text{if } t < T$$

or

$$K + h(t) \ , \quad \text{if } t > T.$$

Let total cost be denoted by TC(t), then the expectation of total cost incurred over one lifetime cycle for one vehicle is

$$\begin{aligned} E[TC(t)] &= \int_o^{20} TC(t)f(t)dt \\ &= \int_o^T [K+c(t)-s(t)]f(t)dt + \int_T^{20} [K+h(t)]f(t)dt \\ &= \int_o^T Kf(t)dt + \int_T^{20} Kf(t)dt + \int_o^T [c(t)-s(t)]f(t)dt + \int_T^{20} h(t)f(t)dt \\ &= K + \int_o^T [c(t) - s(t)]f(t)dt + \int_T^{20} h(t)f(t)dt \ \ldots.(3) \end{aligned}$$

(2) Length of lifetime, L

The actual length of the lifetime of a vehicle will be

t , if $t<T$

or

T , if $t>T$

Therefore the expectation of the length of a lifetime cycle is

$$E[L] = \int_o^T tf(t)dt + \int_T^{20} Tf(t)dt$$

$$= \int_o^T tf(t)dt + T[F(t)]_T^{20}$$

$$= \int_o^T tf(t)dt + T[1 - F(T)] \quad \dots\dots\dots\dots\dots\dots\dots\dots(4)$$

(3) Average cost per lifetime

Divide equation (3) by equation (4) which gives the long-run average cost per unit of time. It is

$$\frac{E[TC(t)]}{E[L]} = \frac{K + \int_o^T [c(t)-s(t)]f(t)dt + \int_T^{20} h(t)f(t)dt}{\int_o^T tf(t)dt + T[1-F(T)]} \quad \dots(5)$$

(4) Assume that the lifetime of motor vehicles are found to be uniformly distributed over (a,b), then $f(t) = 1/(b-a)$ and $F(t) = t/(b-a)$. For simplicity, let $b-a=d$, then $f(t) = 1/d$ and $F(t) = t/d$. Substituting into equation (5) to yield a general formula for long-run average cost for uniformly distributed lifetime, let it be denoted by $G_u(t)$

$$G_u(t) = \frac{K + \int_o^T [c(t)-s(t)] \frac{1}{\alpha} dt + \int_T^{20} h(t) \frac{1}{\alpha} dt}{\int_o^T t \frac{1}{\alpha} dt + T[1-T/d]} \quad \dots\dots\dots\dots(6)$$

Note: For the case of uniform distribution, the range is limited by b-a, so the predetermined T must lie in this range, i.e., $a < T \leq b$. If $T>b$, then $Pr[t > T] = 0$, the equation is invalid.

Example: Suppose that the lifetime of a vehicle was found to be uniformly distributed over (0,12) years and the purchase cost, K = \$50 (in 10,000), operational and maintenance cost c(t), salvage value s(t), and the overtime extra operational cost h(t) all have a function of time, respectively.

$$c(t) = 3.5 + 8.7t$$

$$s(t) = 36 - 3.2t$$

$$h(t) = 5.5t$$

Applying equation (6),

$$G_u(t) = \frac{50 + \frac{1}{12}\int_o^T (3.5 + 8.7t - 36 + 3\cdot 2t)dt + \frac{1}{12}\int_T^{20} 5.5tdt}{\frac{1}{12}\int_o^T tdt + T(1 - T^2/12)}$$

$$= \frac{6.4T^2 - 65T + 3400}{24T - T^2}$$

Taking first derivative of $G_u(t)$,

$$G_u'(t) = \frac{(24T - T^2)(12.8T - 65) - (6.4T^2 - 65T + 3400)(24 - 2T)}{(24T - T^2)^2}$$

$$= \frac{88.6T^2 + 6800T - 81600}{576T^2 - 48T + T^4} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Setting equation (7) equal to zero to solve T, i.e.,

$$88.6T^2 + 6800T - 81600 = 0$$

or

$$T^2 + 76.75T - 920.99 = 0$$

$$\therefore\ T = \frac{-76\ 75 \pm \sqrt{(76.75) + 4(920.99)}}{2}$$

$$= 10.55 \text{ (years)}$$

Next, to verify that T = 10.55, minimize the value of $G_u(t)$, taking second derivative, from equation (7),

$$G''_u(t) = \frac{(576T^2 - 48T^3 + T^4)(177.2T - 6800) - (88.6T^2 + 6800T - 81600)(1152T - 144T^2 + 4T^3)}{(576T^2 - 48T^3 + 4T^4}$$

$$= \frac{-177.2T^5 - 16147.2T^4 - 979200T^3 - 15667200T^2 + 94003200T}{(576T^2 - 48T^3 + T^4)^2}$$

$$G''_u(10.55) = \frac{-177.2(10.55)^5 - 16147.2(10.55)^4 - 979200(10.55)^3 - 15667200(10.55)^2 + 94003200(10.55)}{(576T^2 - 48T^3 + T^4)^2}$$

$$= \frac{1745.6865}{(576(10.55)^2 - 48(10.55)^3 - (10.55)^4)^2}$$

because the enumerator after squaring is always positive. Therefore the value of $G''_u(10.55)$ is also positive; in other words, $T = 10.55$ minimize $G_u(10.55)$.

(5) Assume that the lifetime of a motor vehicle is found to be exponentially distributed with a mean value of (years), then $f(t) = \frac{1}{\lambda}e^{-\frac{1}{\lambda}t}$, $t > 0$, and $F(t) = \int_0^t f(x)dx = 1 - e^{-\frac{1}{\lambda}t}$; substituting into equation (5) to yield a general formula for long run average cost for exponentially distributed lifetime, let it be denoted by $G_e(t)$, then

$$G_e(t) = \frac{K + \int_0^T [c(t) - s(t)] \frac{1}{\lambda} e^{-\frac{1}{\lambda}t} dt + \int_T^{20} h(t)\frac{1}{\lambda} e^{-\frac{1}{\lambda}} dt}{\int_0^T t \frac{1}{\lambda} e^{-\frac{1}{\lambda}T} dt + Te^{-\frac{1}{\lambda}T}}$$

$$= \frac{\lambda K + \int_0^T [c(t) - s(t)] e^{-\frac{1}{\lambda}t} dt + \int_T^{20} h(t) e^{-\frac{1}{\lambda}t} dt}{\lambda^2 [1 - e^{-\frac{1}{\lambda}T}]} \quad \ldots.(7)$$

V. CONCLUSION

In the thirty years after WWII, Taiwan's situation progressed from unstable and bewildered to a well developed economic society with a national income per capita of US$700, highest, excluding Japan, in the Southeast Asia area.

During the developing stage, any economic society experiences various paradoxical situations. Taiwan's auto industry evolved from a handicraft industry to a modern assembly-line production industry in recent years as the domestic booming economy created a potential demand for more cars. The problem with the situation is that the unit cost of a vehicle has tended to be too high. A logical solution to the problem is to merge the military demand and civilian demand in order to produce a more efficient quantity production of vehicles. The AFRC has many problems to be solved. The replacement of administrative vehicles is one which appears not to have been studied thoroughly. In this paper the author stresses a systematic approach to the problem rather than the strict application of a mathematical model.

Furthermore, the suggested replacement policy could also be applied to other transportation organizations. For example, the Taiwan Provincial Bureau of Highways and the Taipei City Bus Systems, both of them operate several thousand passenger buses, and some other private transportation companies; all of them have had experience with the confusion of the replacement problem for years.

For the model addressed above, the distribution of lifetime of vehicles must be observed as well as the cost incurred collected and studied before applying the model. General formulae for the uniformly and exponentially distributed lifetime were derived. Different types of lifetime distribution could also be derived, using the same procedures.

The author eagerly hopes that a validation or modification of the model can be done after some real world data is collected in the future.

When data is available, comparison between the model in this paper and other approaches can also be executed by computer simulations.

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